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Reducing Leakage Occurring in Overturns of Liquid-Carrying Cargo Tanks

Executive Summary Report

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November 1981

Final Report

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16. Abstract

Product retention items on MC 306-type cargo tanks which represent potential leakage points in overturn accidents were identified in pressure tests of 61 cargo tanks at carrier sites and laboratory tests of 119 pressure/vacuum vents. The manhole assembly, loading/unloading venting, and pressure-actuated venting devices were identified as primary leakage sources in overturn accidents.

The results of this survey indicated that: (1) the large carriers were performing systematic maintenance on their cargo tanks, but small carriers were not; (2) maintenance performed on cargo tanks is directed primarily to vehicular components; and (3) most carriers do not perform adequate maintenance on product retention items.

A cargo tank compartment overturn simulator was designed and constructed, then used in 90° and 180° tests of new and used manhole assemblies and venting devices. These tests identified pressure-actuated venting in filler covers and loading/unloading venting as the primary sources of overturn leakage.

Regulation changes were formulated and presented to an industry representation. On the basis of program test results and industry evaluation, changes are recommended to Parts 173, 177, and 178 (49 CFR) to: (1) require leakage checks before tanks are operated, (2) increase frequency and scope of inspections and maintenance, and (3) instill overturn integrity as a construction and maintenance requirement throughout the operating life of MC 306-type tanks.

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1.0 INTRODUCTION

The MC 306-type cargo tank is the major highway transport vehicle used for the movement of combustible and flammable liquids. The MC 306-type category includes prior designations MC 305, 303, 302, 301, and 300.

When this type cargo tank is involved in an accident, a disaster potential of considerable magnitude exists. The disaster potential increases greatly if the cargo tank overturns and cargo leakage occurs and fire and/or explosion results.

Existing regulations (49 Code of Federal Regulations) specify requirements for cargo tank manufacture, operation, maintenance, inspection, repair, and testing. Accident statistics, however, show a high incidence of leakage in overturn accidents and high costs in personal injuries and property damage. This program was conducted to determine the integrity of MC 306-type cargo tanks in overturn accidents and provide recommendations, if any, for increased safety.

1.1 PROGRAM CONCLUSION

CARGO TANK OVERTURN INTEGRITY IS THE ASSURED CAPABILITY OF CARGO TANK STRUCTURES, SYSTEMS, COMPONENTS, SAFETY DEVICES, AND ALL OTHER INTEGRAL AND SUPPORTIVE TANK FEATURES TO RETAIN HAZARDOUS MATERIALS IN OVERTURN ACCIDENTS.

Overturn integrity for cargo tanks is provided by a safety system comprised of components that have product service and control functions under normal operating and loading/unloading conditions. The function of this safety system is a required automatic response of these components in overturns, overfills, and exposure to fire, in which they must perform as product retention items.

Based on the program results summarized in this report, it is concluded that existing systems must be improved in order for MC 306-type cargo tanks to retain their cargoes in overturn accidents.

1.2 CONTRACT OBJECTIVES AND ACCOMPLISHMENTS

The program had four objectives:

1. To assess present maintenance practices and requalification requirements as they affect a cargo tank's continuing product retention capability.

2. To assess existing specifications for manhole covers, fill covers, and other product retention items and identify specific items which represent potential leakage points in overturn accidents.

3. Develop test procedures and engineering drawings for a simulator capable of testing manhole covers and other product retention devices in overturn situations.

4. Develop engineering recommendations to improve cargo tank product retention capabilities that can be incorporated into the cargo tank specification and qualification requirements of the Department.

To achieve the objectives, the following was accomplished:

- The maintenance practices of 10 carriers were surveyed.

- Sixty-one cargo tanks and 119 new and used breather vents were tested under static conditions.

- A 1,500-gallon, rigid-wall, multipurpose overturn simulator was developed and fabricated.

- Using the simulator, 9 manhole assemblies (new, used, and prototype), 4 high-capacity vents, 4 breather vents, overturn rails, and 1 fusible vent were the experiments for 21 dynamic tests. Testing results and proposed regulatory changes were presented to an industry conference for evaluation.

- Regulatory requirements were evaluated throughout as task results became final.

2.0 CARRIER MAINTENANCE PRACTICES SURVEY

The carrier maintenance practices survey furnished data and results which were verified and emphasized in later static and dynamic testing. The minor amount of maintenance done on product retention items showed up in high leakage rates and many instances of poor maintenance quality. The survey of 10 geographically separated carriers included large/small, private/common carrier operations.

The basic features of the 10-carrier survey sample were:

- Eighty-two persons were engaged in maintenance support of 446 cargo tanks, most of which were MC 305's and MC 306's.

- Thirty-seven of these 82 maintenance persons had a total of 437 years of experience in cargo tank maintenance.

The basic findings of the survey were:

- Six of the 10 carriers had the capability to do complete maintenance on all tank features except structural repairs and requalification testing.

- Very few daily vehicle condition reports were sufficiently detailed to facilitate even once-per-shift inspections that would ensure maintenance is notified when repairs are needed.

- Shop inspection and repair systems were formally established and well-supported by internal files; these files revealed that most maintenance is directed to power units and cargo tank running gear.

- Very little maintenance is done on critical components.

- Scheduled maintenance frequency was an extreme variable.

- The two-year visual inspection was well known as a regulatory requirement.

- Most carriers do not perform tank requalification testing; repair agencies provide this service, using a hydrostatic procedure that does not test the filler cover closure.

- The carriers identified manholes, valve operators, adapters, and internal valves as the tank components that require the most attention, repair, and replacement effort.

- Structural maintenance was reported to be the most difficult, but components provided the most maintenance problems.

- New design or design improvement effort would be required to implement most of the recommendations made by carrier personnel to improve cargo tank maintenance and product retention capabilities.

3.0 CARGO TANK AND COMPONENT/SYSTEM TESTING

The carrier survey had revealed the components that require the most maintenance effort, but also that little maintenance is performed on them.

Field and laboratory testing provided a definite indication of the condition of cargo tank components that would be involved in preventing leakage in overturn accidents.

3.1 PRODUCT SERVICE AND RETENTION ITEMS

The following components or structural elements are involved in product service functions of cargo tanks:

- Adapters
- Piping
- Manifolds
- Internal Valves
- Valve Operators
- Compartment Bulkheads
- Manhole Assemblies
- High-capacity Vents
- Breather Vents
- Overfill Sensors
- Vapor Recovery Devices
- Tank Shell

The following components are the key cargo tank features involved in product retention while in transport or in overturn accidents:

- Manhole Assemblies
- High-capacity Vents
- Breather Vents
- Piping (inclusive of internal valves)
- Manifolds
- Adapters

While attention was given to all tank components and structures, emphasis was focused on the above.

3.2 FIELD TESTS

A total of 61 cargo tanks were tested at four major population centers in the conterminous United States. The required pneumatic test procedure was implemented in a two-step (A and B) process, except that test pressure was limited to 1 psi to prevent damage to tank structure.

Test A identified leaks for all compartment system components except the internal valve, high-capacity vent, and breather vent (breather vent leakage was determined in laboratory tests). Test B identified internal valve and high-capacity vent leaks.

A total of 61 cargo tanks (187 compartments) were tested; most (56) were MC 306 and MC 305 tanks. The tanks were manufactured in the 1957-1978 period, and the type totals were as follows:

MC 307	MC 306	MC 305	MC 303	MC 302	TOTAL
2	34	22	1	2	61

Loading system types were near equal among the 61 tanks (31 top-loaded and 30 bottom-loaded). Also, the majority of the tanks:

- Had mechanically-operated internal valves (78%).
- Were not equipped for vapor recovery (62%)
- Were not manifolded (74%)

FIELD TESTING RESULTS

A total of 451 leaks were detected in the 187-compartment, 61-tank test sample. The 34 MC 306's provided 294 leaks and 143 leaks came from the 22 MC 305's.

The primary leakage sources were as follows, with number of leaks and percent of total 451 indicated:

MANHOLE ASSEMBLY
256 leaks (57%)

INTERNAL VALVE
72 leaks (16%)

VAPOR RECOVERY SHROUD
10 leaks (2%)

CLEANOUT OPENING
16 leaks (4%)

HIGH-CAPACITY VENT
46 leaks (10%)

LIQUID-LEVEL SENSOR
21 leaks (5%)

WELD AND SHELL CRACKS
21 leaks (5%)

INLET PLUG, DISCHARGE OUTLET, ADAPTER, AND MANIFOLD
9 leaks (2%)

About 80% of the 451 total leaks had tank top sources and 20% had tank bottom sources as shown in Figure 1. Distribution of the 256 manhole assembly leaks is shown in Figure 2.

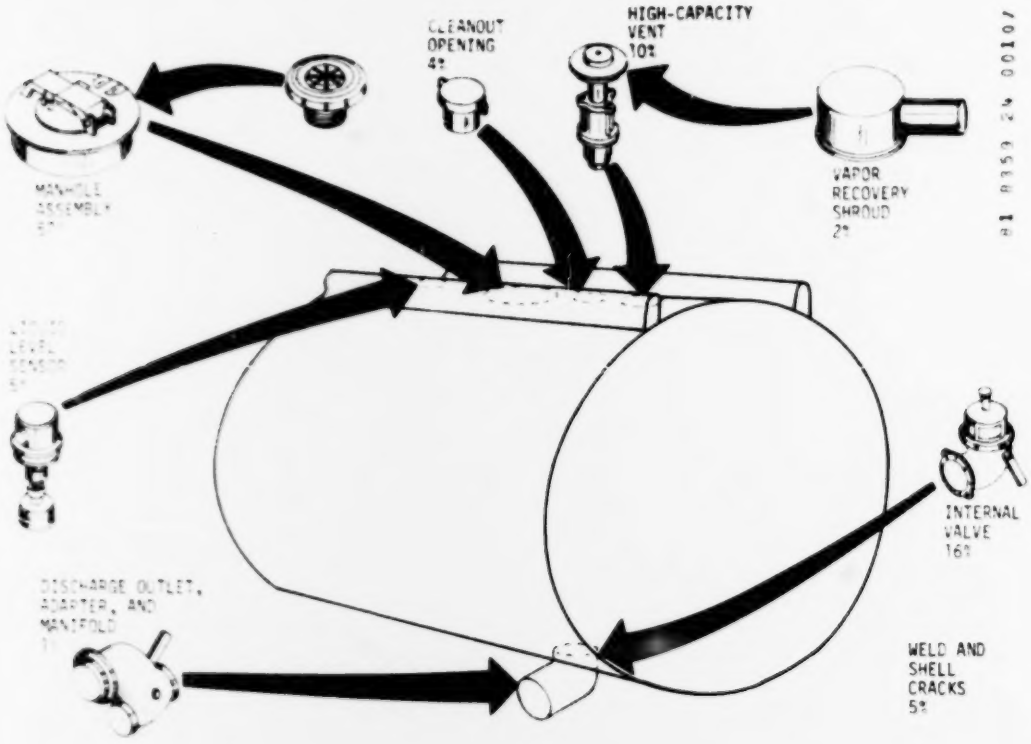

FIGURE 1. TOTAL LEAK DISTRIBUTION.

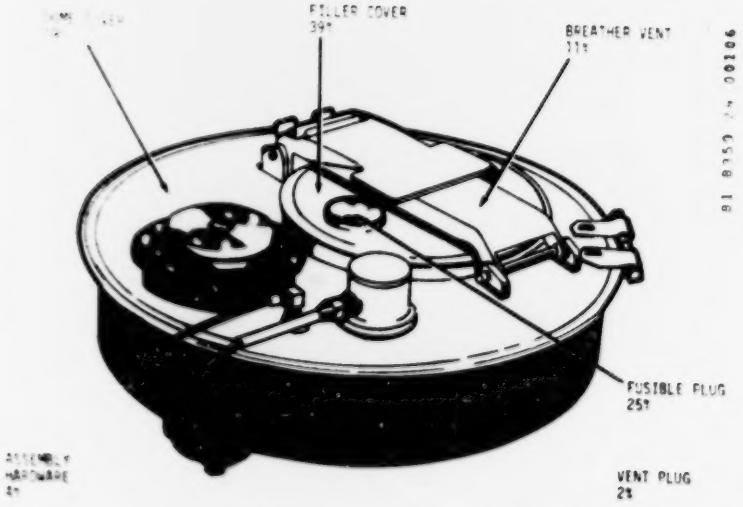

FIGURE 2. MANHOLE ASSEMBLY LEAKS.

The average leaks per tank was 7.39 and the average per compartment was 2.41. These averages would have been higher if point-by-point tests could have been completed on all compartments. Tests were aborted on 70 compartments because:

- There were such large leaks that 43 compartments could not be pressurized.
- There was product remaining in 27 "empty" compartments that prevented completion of the test procedure.

3.3 LABORATORY TESTS

During the field tests, breather vents were rendered inoperative in accord with current test procedures. The vital role these vents have in routine operation and their known propensity to leak in overturn accidents made it necessary to test them under representative overturn conditions in order to accomplish a complete compartment system evaluation.

A total of 16 types of vents were tested. The test sample consisted of 119 vents; 16 were new (acquired from repair agencies and manufacturers) and 103 were used (acquired from tanks in use or tanks in repair agencies, but not for vent replacement).

On the basis of 833 tests with 119 new and used breather vents (16 types), the average leakage through the vent device was determined to be a steady stream not less than 1/8" up to 1/2" diameter.

3.4 DYNAMIC OVERTURN SIMULATION TESTING

The field and laboratory testing had provided data which indicated the sources from which leakage could be expected in cargo tank overturns. These data were based on static test methods which effectively quantified leakage on a probability and average basis. Static tests do not, however, reveal the forces that accompany or induce leakage. Dynamic test data were thus necessary to determine the impact environment which causes the component/system to actuate the design mechanisms which produce or inhibit leakage.

To acquire the dynamic test data, the cargo tank compartment overturn simulator shown in Figure 3 was used to conduct 21 tests. The simulator provides repeatible 90° and 180° tests without sustaining structural deformation.

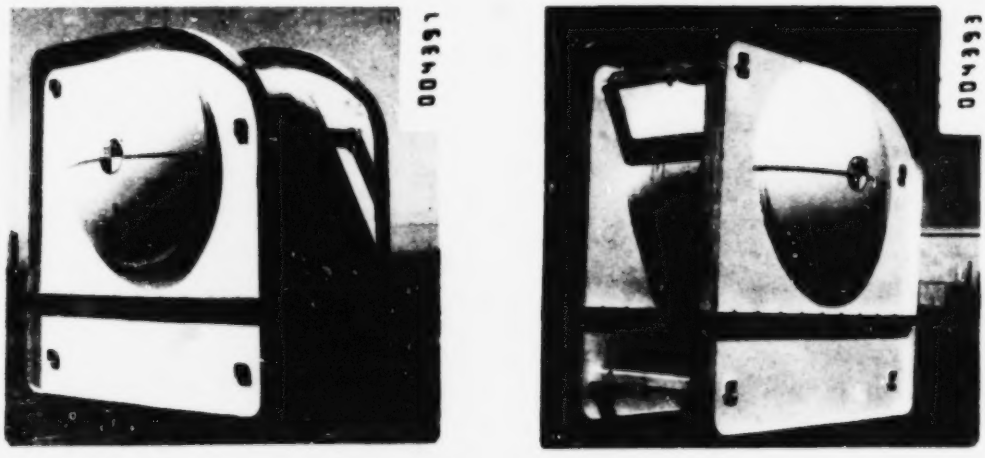

FIGURE 3. COMPARTMENT OVERTURN SIMULATOR.

FIRST TEST SERIES

The series consisted of eight tests, all in the 90° overturn mode. The tests were conducted to:

1. Determine the baseline performance characteristics of new cargo tank product retention components.

2. Determine the performance characteristics of used components so that a new/used comparison could be made.

3. Obtain data for presentation to industry that would facilitate an evaluation of proposed 49 CFR changes concerning manufacture, maintenance, and operation of cargo tanks.

The experiments for this series consisted of four new and four used manhole assembly/breather vent installations.

The test fluid was Stoddard solvent, and test results were recorded as leakage that occurred when the simulator impacted the sod surface (dynamic) and leakage that occurred with the simulator at rest after 90° rotation (static).

RESULTS OF FIRST TEST SERIES

The most obvious result of these tests is that significant leakage occurred on initial impact in all eight tests. Generally, on impact test fluid was released by the pressure-actuated venting (PAV) in the filler cover. In liquid spray form, it covered an area approximately 15 feet to either side and above the simulator and 15-18 feet ahead of the manhole cover. Most of the wetness was concentrated just beneath and in front of the manhole cover, with only droplets reaching the periphery of the area described. Figure 4 presents an approximation of this pattern.

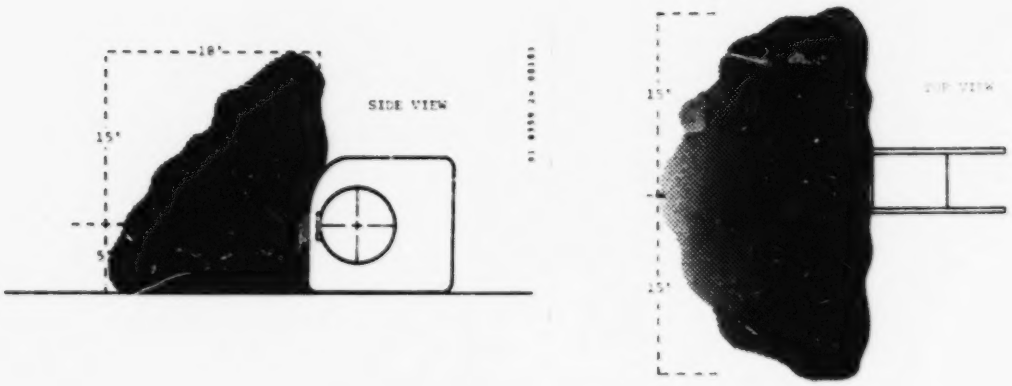

FIGURE 4. APPROXIMATION OF LEAKAGE SPRAY PATTERN.

Static leakage was collected for one minute after each test. There was static leakage from either the filler cover or breather vent in each test. The amount of leakage varied from drips to 6.5 gal./min.

For the eight tests, the average peak pressure at the manhole experiment on impact was 15.6 psig. The duration of the event during which pressure exceeded 3 psig and allowed impact spray leakage was approximately 43 msec.

Manhole assembly structural deformation was checked after each test. There was no visible structural deformation apparent after the tests.

Whether an experiment was new or used did not serve to inhibit the initial impact leakage or static leakage.

It is estimated that the amount of fluid that leaked on impact was 1-1/2 - 2 gallons per test. This amount of fluid (if it is a flammable product with a relatively low flash point) in a mist form has a high ignition potential. This potential increases significantly on the basis of the number of compartments a cargo tanker has.

SECOND TEST SERIES

The series consisted of 13 tests, including a fire test. Two tests were in the 180° overturn mode and the remainder were 90° overturn tests.

The tests were conducted to:

1. Determine the performance of manhole assemblies with the PAV mechanism inerted.

2. Test a prototype manhole assembly.

3. Determine the influence of overturn rails on leakage spray patterns.

4. Determine leakage occurrence in 180° tests.

5. Demonstrate improved leakage prevention for old manhole assemblies with a new gasketing technique.

6. Determine dynamic performance of breather vents.

7. Determine fire severity of impact leakage from a compartment.

Stoddard solvent was the test fluid in all but one test in which gasoline was used.

RESULTS OF SECOND TEST SERIES

The first test series had one basic objective - determine the influence of PAV on manhole leakage. The leakage pattern shown in Figure 4 was consistent, and experiment condition (new or used) had no effect. This same leakage effect also took place in the second series in all tests with new or used manhole assemblies with PAV integrated in the filler cover.

Leakage Summary

Like the first test series, the second series included both new and used manhole assemblies and vents. One prototype assembly was also tested.

Dynamic and static leakage was a determination in all 13 tests. Dynamic (impact) leakage occurred as summarized below by leakage source and number tests:

High-Capacity Vents	Breather Vents	Filler Cover PAV	Filler Cover Without PAV or PAV Inerted
4 Tests	4 Tests	8 Tests	2 Tests

Static (post-impact) leakage occurred as summarized below by leakage source and number tests:

High-Capacity Vents	Breather Vents	Filler Cover PAV
3 Tests	5 Tests	2 Tests

Dynamic and/or static leakage occurred in all 13 tests.

The data for the 90° tests were averaged to determine the time segment of the impact event in which pressure reaches and/or exceeds 3 psig, the actuation level for PAV and high-capacity vents. It was revealed that pressure at the manhole location exceeds 3 psig for a 55 msec period.

Manhole Structure Deformation

There was no visible structural deformation in any of the manhole assemblies as a result of internal fluid pressure rises.

Fire Test - 90° Overturn Simulation

The test fluid was 1,500 gallons of gasoline. Open ignition sources were provided in the spray release area.

On impact a typical filler cover PAV spray release pattern (Figure 4) developed, and ignition occurred at 838 msec after impact.

The vapor nature of the spray leakage produced a fireball which quickly dissolved to black smoke and flame mix, typical of petroleum fires, and spread to cover the spray pattern area. Figure 5 shows the fire at 2.6 seconds after impact, and the fire is still propagating. It reached maximum development at 3.8 seconds, then began to recede.

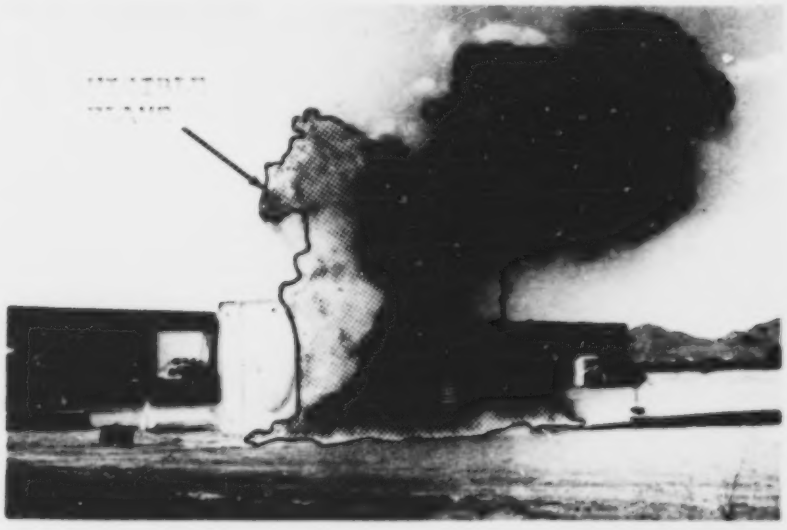

FIGURE 5.
FIRE TEST.

The fireball size and ground fire coverage was as follows:

	Fireball	Ground Fire
Maximum Height	21.1 feet	*
Maximum Depth	11.8 feet	17.2 feet
Maximum Width	20.6 feet	41.9 feet

*Visible flame and smoke mix precluded determination.

Average temperatures recorded during the 4 seconds after impact were as follows:

At Manhole	6 Feet in Front of Manhole	15 Feet in Front of Manhole
1217 °F	625° F	325° F

The fire potential of the amount of spray leakage from a manhole assembly with PAV was demonstrated. The fire covered an area 20 feet to either side of the simulator and 17 feet ahead of it.

4.0 INDUSTRY EVALUATION

A meeting was held to brief industry representatives on program results and obtain their evaluation of proposed changes to regulatory requirements which covered:

1. Production and repair of cargo tanks.
2. Maintenance and operation of cargo tanks.

In addition to the proposed regulation change recommendations, industry was asked to evaluate and comment on the following:

1. Gasket and seal degradation and maintenance
2. Future tank innovations
3. Maintenance concepts

The 25 cargo tank management and/or technical persons who attended represented four cargo tank manufacturers, seven tank component manufacturers, three tank repair agencies, six carriers (two private and four common), and the American Petroleum Institute (API) and National Tank Truck Conference (NTTC).

The attendees were assigned to committees and asked to evaluate and provide an oral report on the technical feasibility and cost implications (per tank) of regulatory changes and maintenance and design concepts.

4.1 REGULATORY CHANGES

Regulatory changes included those affecting:

- Production and repair of cargo tanks
- Maintenance and operation of cargo tanks

Industry response varied on the basis of committee professional interests. In general there was concurrence in changes that would result in overall safety and uniform practices. There was mostly nonconcurrence for changes that would require new designs or increased technical performance characteristics. The effort the committees devoted to rewriting the changes and the frankness of the viewpoints presented and supported were noteworthy.

4.2 MAINTENANCE AND DESIGN CONCEPTS

Each committee was asked to evaluate and provide an oral report on questionnaires dealing with:

- Gasket and seal degradation and maintenance
- Future tank innovations
- Maintenance concepts

The industry's evaluation left little doubt that gasket materials are affected by no-lead additives and other possible product effects.

Some ideas that represent new techniques for manhole assemblies, venting, shell materials, and construction were summarized as future tank innovations. The committees were then asked to evaluate them for application to a prototype cargo tank.

Some of the more significant responses were as follows:

1. Elimination of the filler cover (with bottom loading): Majority response was no, citing need for PAV in fires and rollovers.
2. Downward-opening filler covers: Equal yes and no responses, but termed inpractical for various reasons including maintenance problems.
3. Changes in closure mechanism for breather vents: General nonconcurrence because of costs and feeling that existing mechanisms are adequate.
4. Use of overturn rails for venting: Response was unfavorable citing technical design problems and possible product contamination effects.
5. Addition of external vertical or longitudinal stiffeners to MC 306 shells: Majority unfavorable response was based on creation of stress risers, increased puncture probability, and advocation of insulation as an alternative.

Various maintenance concepts were evaluated, but general non-concurrence resulted based on:

1. Hazards related to working on top of tank.
2. Other more effective methods available.
3. Frequency (quarterly too often).

A recommendation was presented to change the two-year visual inspection to an annual test inspection involving a 2 psig pressure test. Manufacturers concurred provided it was not a duplication of vapor recovery testing, also saying test to the TTMA recommended practice for vapor recovery. Carriers recommended a pressure test every two years, citing high costs. Repair agencies agreed with the 2 psig test but not on an annual interval.

5.0 COMPLIANCE ANALYSIS AND RECOMMENDED REGULATORY CHANGES

5.1 COMPLIANCE ANALYSIS - PRODUCT RETENTION ITEMS

The product retention items on which evaluation and test data were collected have defined performance requirements for both operating and emergency modes, treated as the overturn mode here. The data obtained from static and dynamic testing allowed regulatory compliance assessment under four conditions, as defined below:

Condition	Tank Mode
1.	Tank in upright operating mode - Static*
2.	Tank at 45° stage of 90° overturn; all retention items in contact with lading - Dynamic**
3.	Impact at 90° - Dynamic**
4.	Tank at rest in 90° overturn position - Static*

*No fluid pressure surge. **Under fluid pressure surge.

Product retention items or functions were assessed for performance under the above four conditions.

Criteria for noncompliance are as follows:

1. A non-design opening of serious dimensions probably exists based on conditions repeatedly observed during static field testing, though the component or tank function is not in contact with the lading.

2. Leakage probability is supported by either static field tests or laboratory tests or dynamic tests or observed leakage after dynamic tests.

Considering all information available from the maintenance practices survey, testing, and accident data analysis, except for manhole assembly structure, none of the assessed items/functions would provide safe system performance under all four conditions.

From an overall viewpoint, noncompliance with performance requirements exists, as summarized below:

SUMMARY OF COMPONENT/FUNCTION COMPLIANCE ANALYSIS

	Compliance (= Yes) Assessment for Condition			
	1-Static	2-Dynamic	3-Dynamic	4-Static
Manhole Assy. Structure	Yes	Yes	Yes	Yes
Manhole Closure Integrity	No	No	No	No
Filler Cover Gaskets	No	No	No	No
Breather Vents	Yes	No	No	No
High-capacity Vents	Yes	Yes	No	No
Fire Exposure Emerg. Venting				
PAV	Yes	Yes	Yes*/No**	Yes*
Fusible	Yes	No	No	No
Internal Valves	No	No	No	No

*Design function.
**Leakage past device.

5.2 RECOMMENDED REGULATORY CHANGES (49 CFR)

The regulatory changes recommended here are based on the findings from the maintenance practices survey (Section 2.0), the results of all testing conducted during the program (Section 3.0), and the industry evaluation (Section 4.0).

5.2.1 Inspection Requirement - Part 177

The results obtained during this program support the following:

1. An annual inspection (with a pressure test every other year) will provide a significant increase in product retention capability.

2. The costs of an annual inspection are not excessive.

3. The expertise available in the cargo tank maintenance force can accomplish pressure testing without incurring safety hazards above those encountered in normal tank maintenance and performing the present two-year external visual inspection.

It is therefore recommended that regulations be changed to require an annual inspection of each MC 306-type cargo tank, with a 2 psig pressure test required every other year.

It is further recommended that the hydrostatic or pneumatic testing procedure, as pertains to MC 306-type tanks, be changed as follows:

1. Stipulate that the manhole filler cover is included among all closures, and that discharge pipe outlets are to be openable so that internal valve leakage can be detected.

2. Change the pressure hold time from 10 to 5 minutes.

5.2.2 Transport Requirements - Part 177

One way of reducing and/or preventing leakage in transport is to require that a quick visual inspection be made and recorded before a cargo tank vehicle can be driven after each loading.

Therefore, recommend that:

1. All manhole closures on the cargo tank are closed and secured as verified by visual inspection; and

2. All valves and other closures in liquid discharge systems are closed and free of leaks as verified by visual inspection.

5.2.3 Tank Specification Requirements - Part 178

General Specification

Add a requirement that systems and components of the tank devoted to product containment and retention must provide assured capability for maintaining overturn integrity throughout the operating life of the tank when maintained.

Accident Damage Protection

Recommend MC 306-type tanks include:

1. Accident damage protection for venting devices.

2. Vapor recovery lines capable of retaining product under static head pressure of the tank in any position.

MC 306 General Requirements

The following changes are recommended as additional provisions for MC 306-type cargo tanks:

1. Require that parts, accessories, gaskets, components, and materials used to comprise the product retention items be capable of periodic design performance verification.

2. Require that all product retention items used in construction be capable of having original performance capabilities be verified by periodic inspection and testing.

3. Require availability to cargo tank operators of technical instructions for maintaining product retention items for assured overturn integrity.

4. Require that design pressure (maximum allowable working pressure) be not less than 3 psig.

MC 306 Manhole Requirements

The existing design limit (9 psig) should be increased and the average test pressure sustained (13 psig) be accepted as the design limit.

Secure closure of the manhole is essential if the primary leakage source shown in dynamic testing is to be prevented or minimized.

The following changes are recommended:

1. They (manholes) shall have structural capability of withstanding internal fluid pressures of 13 psig without permanent deformation.

2. Safety devices to prevent the manhole and/or fill cover from opening when internal pressure is present shall be provided.

MC 306 Venting Requirements

Normal Venting

The program results and safety considerations necessitate the following recommendation:

Leave stand: Pressure and vacuum vents shall be designed to prevent loss of liquid through the vent in case of vehicle overturn.

Add: Sealing to prevent liquid loss will commence when the vent comes into contact with the lading as a result of internal liquid surge or when the tank vehicle commences overturn.

Loading/Unloading Venting

The following changes are recommended:

Delete: "Unless effective protection against overfilling is made,"

Leave stand: "the pressure vent shall also have sufficient liquid capacity to prevent the pressure from exceeding 3 psig in case of accidental overfilling."

Add: All high-capacity vents must be adaptable to vapor recovery installation (whether installed during manufacture or tank modification), yet allow the vapor recovery apparatus to be disconnected to facilitate pressure tests of the compartment.

Emergency Venting for Fire Exposure

Based on testing conducted during this program and considering all information presented, it is recommended that pressure-actuated devices shall be designed so as to prevent leakage past the device in case of surge or vehicle upset. They shall function in case of pressure rise as a result of fire exposure under any condition of vehicle rollover attitude.

*U.S. Government Printing Office : 1982 -361-428/2016